CHAPTER 16

FOUNDATION DESIGN

A footing is the interfacing element between the superstructure and the underlying soil or rock. The loads transmitted from the superstructure to the underlying soil must not cause soil shear failure or damaging settlement. It is essential to systematically consider various footing types and to select the optimum alternative based on the superstructure and the subsurface conditions.

- Shallow Foundations - spread footings
- Deep Foundations - drilled shafts, pile foundations, or caissons

Because short piles are generally undesirable, the designer should specify excavation to rock rather than placing short driven piles. Where the depth from the bottom of the footing to rock is minimal, the designer has four options for determining the optimum foundation alternatives.

- Specifying sub-foundation backfill from the rock surface to the bottom of the footing.
- Using sub-foundation concrete instead of backfill where the depth to bedrock is shallow. Dimensions of the sub-foundation concrete should be shown in the drawings.
- Lowering the bottom of the footing (creating a thicker footing).
- Constructing a taller pier or abutment.

The designer must specify excavation into the rock to key the footing into the rock and to establish a suitable level-bearing surface. The excavation in the rock can be full width of the footing or be benched. Any footing that exceeds 3 ft. in depth must have vertical reinforcement to prevent cracking.

16.1 Subsurface Investigations

A proper design of a structure foundation requires thorough knowledge of the subsurface conditions at the structure site. The investigation should consist of subsurface investigation (borings, on-site testing, and sampling); laboratory testing; geotechnical analysis of all data; and design recommendations.

NOTE: Soil Classifications - District uses the **AASHTO** definitions to classify soils.

16.2 Requests for Borings

The cost of a boring program is comparatively small in relation to the overall structure cost. In the absence of adequate boring data, the design engineer must rely on extremely conservative designs with high safety factors:

- A location map showing the site with respect to the general area.
- A plan of the existing structure or the proposed structure showing the approximate locations of the substructure units and the borings requested.
- The plan should show the existing and proposed right-of-way limits. When possible, location controls should be shown on the plan to assist the boring crew to accurately locate test holes by station and offset and to record ground surface elevations.

In preparing the request, the designer should consider the following requirements for borings:

- The designer must specify a minimum of one boring per substructure unit.
- A minimum of two borings per structure is required even where multi-plate and other large pipes are planned.
- Pier and abutment footings over 100 ft. in length require additional borings.
- The borings for adjacent footings should not be located in a straight line but should be staggered at the opposite ends of adjacent footings, unless multiple borings are taken at each footing.
- Where rock is encountered at shallow depths, additional borings or other investigation methods such as probes and test pits may be needed to establish the rock profile.
- Where muck is encountered at shallow depths, additional borings or other investigation methods may be needed to determine muck excavation quantities.

16.3 Ground Water Monitoring

Accurate ground water level information is needed for the estimation of soil densities, determination of effective soil pressures, and preparation of effective soil pressure diagrams. This information is vital for performing foundation design. Water levels will indicate possible construction difficulties that may be encountered during excavation and the level of dewatering effort required.

When the borings are made, the drillers will record the ground water elevation. This elevation may not accurately represent water table conditions for the entire year. The designer may request short- and long-term ground water elevation monitoring. Short-term monitoring is normally performed at 24-hour, 48-hour and 72-hour increments. Long-term monitoring will require installation of monitoring wells at the site.

16.4 Geotechnical Reports

Geotechnical reports are required for major structures or where foundation problems are anticipated. The reports shall include the following information:

- Summary Of The Findings
- Plan View Of The Structure Showing The Location Of The Borings
- Boring Logs
- An Evaluation Of The Borings
- Foundation Type Recommendation.

The Recommendation For All Foundations Should Include:

- Soil Parameters, Including Depth, Thickness And Variability Of Soil Strata, Identification And Classification Of Soils, Shear Strength, Compressibility, Stiffness, Permeability, Frost Susceptibility, And Expansion Potential
- Rock Parameters, Including Depth To Rock, Identification And Classification Of Rock, Rock Quality (I.E., Soundness, Hardness, Jointing, Resistance To Weathering, And Solutioning), Compressive Strength, And Expansion Potential
- Presence Of Boulders, If Encountered
- Settlement Considerations Including Required Waiting Period

16.5 Foundation Reports

Foundation reports are required for all structures and shall include:

- Soil Bearing Capacity
- Type Of Foundation
- Bottom Footing Elevation
- Settlement Considerations Including Required Waiting Period
- Cofferdam Requirements, If Needed
- Any Construction Instrumentation And Monitoring Requirements
- Anticipated Scour Depth
- Slope Stability

If Piles Are Recommended, The Recommendations Should Also Include:

- Type Or Types Of Piles
- Size Of Pile
- Design Bearing Capacity Of The Piles
- Proposed Pile Lengths
- Minimum Pile Tip Elevation (Even If It Is Higher Than The Final Tip Elevation)
- Ultimate Design Pile Capacity For Drivability Through The Estimated Scour Layer

16.6 Spread Footing Foundations

It is necessary to consider the feasibility of spread footings in any foundation selection process. Spread footings are generally more economical than deep foundations (piles and caissons). Pile foundations should not be used indiscriminately for all subsurface conditions or for all structures. There are subsurface conditions where pile foundations are difficult to install and others where they may not be necessary.

In the design of continuous-span bridges, the designer must be aware of the possibility of settlement of the earth below footings. If long-term differential settlement due to dead load is expected to exceed ½ in. or if total long-term settlement is expected to exceed 1 in., a pile foundation is required.

Often the major design consideration when faced with a settlement problem is the time involved for the settlement to occur. Low-permeability clays and silt-clays can take a long time to consolidate because the water must be squeezed out before the consolidation is complete.

The two most common methods of accelerating settlement are:

- Applying A Surcharge And/Or
- The Use Of Sand Or Wick Drains In The Subsoil.

16.7 Piles Foundations

Piles should not be used where the depth to bedrock is less than 10 ft. In these cases, it is difficult to develop adequate lateral stability.

16.7.1 Selection of Pile Type

In addition to the considerations provided herein, the conditions posed by the specific project location and topography must be considered in any pile selection process. Following are two of the more commonly encountered conditions:

- Driven piles may cause vibration damage to adjacent structures and property.
- Waterborne operations may permit the use of longer pile sections because longer piles can be barged to the site.

Although one pile type may emerge as the only logical choice for a given set of conditions, more often several different types may meet all the requirements for a particular structure. In such cases, the final choice should be made on the basis of an analysis that assesses the costs of alternative pile types. This would include uncertainties in execution, local contractor experience, time delays, cost of load testing programs, as well as differences in the cost of pile caps and other elements of the structure that may differ among alternatives. The cost analysis should be based on recent bid prices. For major projects, alternate foundation designs should be considered for inclusion in the contract documents if there is a potential for substantial cost savings.

Protection is needed for steel and concrete piles where they are exposed. Protection should extend at least 5 ft. below stream bottom or ground surface. Steel piles should not be used for structures over water.

16.7.2 Pile Types

Load bearing piles can also be classified on the basis of their method of load transfer from the pile to the soil mass. Load transfer can be by friction, end bearing or a combination.

Load-bearing piles of various materials and design characteristics are commonly used. The types of load-bearing piles used are:

- Precast, Prestressed Concrete Piles,
- Precast-Prestressed Concrete Cylinder Piles,
- Cast-in-Place Concrete Piles,
- Steel H-Piles, and
- Timber Piles.

16.7.3 Precast-Prestressed Concrete Piles

- Precast-prestressed concrete piles are recommended for use as piers over water. This is the preferred choice. The minimum preferred size is 12 in. for abutments and 18 in. for piers.
- Precast concrete piles are usually of constant cross section. Concrete piles are considered non-corrosive but can be damaged by direct chemical attack (e.g., from organic soil, industrial wastes or organic fills), electrolytic action (chemical or stray direct currents), or oxidation. Concrete can be protected from chemical attack by use of special cements or special coatings.
- Prestressed concrete piles are generally suitable for use as friction piles where driven in sand, gravel or clays. They are suitable for driving in soils containing boulders when designed for it. A rock shoe attached to the pile tip allows penetration through obstructions. Prestressed

concrete piles are capable of high capacities when used as point bearing piles.

- This pile consists of a configuration similar to a conventional reinforced concrete pile except that the longitudinal reinforcing steel is replaced by the prestressing steel. The prestressing steel is in the form of strands and is placed in tension. The prestressing steel is enclosed in a conventional steel spiral. In designing prestressed concrete piles for piers, the designer must specify special spiral reinforcement. Normal spiral reinforcement is used for piles fully embedded in soil. Such piles can usually be made lighter and longer than normally reinforced concrete piles of the same rigidity.
- Prestressed piles are pre-tensioned and are usually cast full length in permanent casting beds. The primary advantage of prestressed concrete piles versus conventional reinforced concrete piles is durability. Because the concrete is under continuous compression, hairline cracks are kept tightly closed and thus prestressed piles are usually more durable than conventionally reinforced piles. Another advantage of prestressing (compression) is that the tensile stresses that can develop in the concrete under certain driving conditions are less critical.
- Splicing of precast-prestressed concrete piles is not recommended. In cases where piles must be driven to an elevation lower than the bottom of the cap to achieve bearing, cap heights may be increased to accomplish the design with approval of the Bridge Design Engineer.

16.7.4 Precast-Prestressed Concrete Cylinder Piles

Precast-prestressed concrete cylinder piles are post-tensioned piles cast in sections, bonded with a joint compound, and then tensioned in lengths containing several segments. Special concrete is cast by a process unique to cylinder piles that achieve high density and low porosity; the pile is virtually impervious to moisture. Cylindrical piles have good rigidity for long unsupported lengths.

Results of chloride ion penetration and permeability tests on prestressed cylinder piles indicate that the spun cylinder piles have excellent resistance to chloride intrusion. Generally cylinder piles are used for pile bents. The piles typically extend above ground and are designed to resist a combination of axial loads and bending moments. Diameters of 36 in. to 54 in. may be used.

16.7.5 Cast-in-Place Concrete Piles

In general, cast-in-place concrete piles are installed by driving steel shell pipes or by drilling shafts with casings or slurry. The length of cast-in-place concrete piles is not as critical as for precast-prestressed concrete piles.

Reinforcing of the pile length is required to provide adequate capacity. If the pile is fully embedded into soil, the minimum length of the pile reinforcement cage will be 6 ft. In piles used for pile bents, the reinforcing cage must extend a minimum of 10 ft. below the point of fixity. The designer must consider the relationship between pile reinforcement and the location of tapered pile sections. Normally, the reinforcement cage will not be tapered. The designer must properly select a tapered pile section when considering the termination point of the reinforcement cage.

NOTE: Due to environmental and maintenance considerations, the designer should not specify cast-in-place piles for locations over water.

16.7.6 Steel Shell Piles

Cased fluted steel shell piles filled with concrete are the most widely used type of cast-in-place concrete pile. After the shell has been driven and before concrete is placed, it is inspected internally for its full length. Reinforcing steel is required to provide a positive connection to the footing. Reinforcing steel may also be used to provide additional bending capacity.

Shells are best suited for friction piles in granular material. Fluted steel shells are utilized in a shell thickness of 3-gage to 7-gage. The fluted design has two primary functional advantages: It adds the stiffness necessary for handling and driving lightweight piles, and the additional surface area provides additional frictional resistance. Reinforcing steel is placed in the shells prior to placing the concrete

16.7.7 Steel Pipe Piles

Pipe piles usually consist of seamless, welded or spiral welded steel pipes. The pipe sizes used are 12 to 14 in. diameters. The designer must specify the grade and thickness of steel for the pipe.

Pipe piles are driven with closed ends and are always filled with concrete. A closed-ended pile is generally formed by welding a flat plate of ½ to ¾ in. or a conical point to the end of the pile. When pipe piles are driven to weathered rock or through boulders, a cruciform end plate or a conical point with rounded nose is often used to prevent distortion of the pile.

Pipe piles are spliced by using full penetration butt welds. The discussion presented under H-piles on corrosion is also applicable to pipe piles. Steel pipe piles can be used as friction, end bearing or rock-socketed piles. They are commonly used where variable pile lengths are required because splicing is relatively easy. These piles should not be used where the depth to bedrock is less than 10 ft.

16.7.8 Steel H-Piles

Steel H-piles consist of rolled wide flange steel H-sections. They are manufactured in standard sizes with nominal beam depths in the range of 8 in. to 14 in. H-piles result in small relative volume displacement during driving, which may be advantageous when driving in proximity to other structures or buildings.

Steel H-piles commonly conform to ASTM-A36 Specifications. H-piles are not used where they will be exposed to the elements. H-piles are normally used only where fully embedded in soil to support footings. One such application is between footings and relatively shallow bedrock. These piles should not be used where the depth to bedrock is less than 10 ft.

Splices are commonly made by full penetration butt welds. The splice should be as strong as the pile. Proprietary splices are also used for splicing H-piles. A steel load transfer cap is not required if the top of the pile is adequately embedded in a concrete cap. 12 in. embedment is preferred, although 9 in. embedment may be used with proper justification and approval.

Pile points are required for driving H-piles through dense soil or soil containing boulders. Pile points are also used for penetration into a sloping rock surface. Proprietary pile points welded to pile tips are commonly used. H-piles are suitable for use as end bearing piles, and occasionally as combination friction and end-bearing piles.

NOTE: Use of pile points must be approved by the Bridge Design Engineer.

Because H-piles generally displace a minimum of material, they can be driven more easily through dense granular layers and very stiff clays. The problems associated with soil heave during foundation installation are often reduced by using H-piles. H-piles are commonly used for any depth because splicing is relatively easy.

16.7.9 Timber Piles

Timber piles may be used as pier fenders in waterways. They are not recommended for use in foundation design in the District. Timber piles are made from Southern yellow pine or Douglas fir trees. For hard driving, the tip should be provided with a metal shoe. Where a timber pile is subjected to alternate wetting and drying or located in the dry above the water table, the service life may be relatively short due to decay and damage by insects. Even piles that are permanently submerged can suffer damage from fungus or parasites.

Piling in a marine environment is also subject to damage from marine borers. Consequently, all timber piles specified for permanent structures will be treated. The most common method of protection is pressure creosote treatment, but either creosote or chromated copper arsenate (CCA) treatment may be required. Other treatments specified by the American Wood Preserver's Association may be considered when approved by the Bridge Design Engineer. The designer should specify the desired treatment.

Driving of timber piles often results in the crushing of fibers on the driving end (brooming); this can be controlled by using a driving cap with cushion material and metal strapping around the butt. Timber pile splices are generally undesirable. Timber piles are best suited for use as friction piles in sands, silts and clays. They are not recommended as piles to be driven through dense gravel, boulders, or till, or for end-bearing piles on rock because they are vulnerable to damage at the butt and tip in hard driving.

16.7.10 Drilled Shaft Foundations

A drilled shaft is formed by boring an open cylindrical hole into the soil and subsequently filling the hole with concrete. Excavation is accomplished usually by a mobile drilling rig equipped with a large helical auger or a cylindrical drilling bucket. Once in place, a drilled shaft acts essentially like a driven pile, except that the behavior under load may differ because of the dissimilar geometries and installation techniques. The following special features distinguish drilled shafts from other types of foundations:

- Unlike a displacement pile, the drilled shaft is installed in a drilled hole.
- Wet concrete is cast and cures directly against the soil forming the walls of the borehole. Temporary casing may be necessary for stabilization of the open hole and may or may not be extracted.
- The installation method for drilled shafts is adapted to suit the subsurface conditions.
- Other terminology commonly used to describe a drilled shaft includes: drilled pier, drilled caisson, and bored pile.

16.7.11 Types of Drilled Shafts

The five categories of drilled shaft foundations are defined by their diverse methods of load transfer. Generally, the load-carrying capacity is obtained from load transfer to the soil from the shaft or the base or a combination of both, as described below:

- Straight shaft, end-bearing drilled shaft. Load is transferred by base resistance only.
- Straight shaft, side-wall-shear or friction drilled shaft. Load is transferred by shaft resistance only.
- Straight shaft, side-wall-shear and end-bearing drilled shaft. Load is transferred by a combination of shaft and base resistance.
- Belled or under-reamed drilled shaft. Load is transferred by the bell in end-bearing. Shaft resistance may be considered, depending on the dimensions of the drilled shaft and overburden material.
- Straight or belled drilled shaft on hard soil or rock. Shaft resistance may be considered under some circumstances, with the approval of the Bridge Design Engineer.

16.7.12 Application of Drilled Shafts

The drilled shaft is usually employed as a deep foundation to support heavy loads or to minimize settlement. Because of the methods of construction, it is readily applied to soil that is above the water table, or soil that is nearly impermeable, and to profiles where rock or hard soil is overlaid by a weak stratum. With suitable construction techniques and equipment, the drilled shaft can be used in less favorable conditions.

Casing or bentonite slurry can be employed to prevent caving or deformation of loose or permeable soils. The methods of construction can be adapted to severely restricted conditions using specialized equipment. Often, drilled shafts are used where piles cannot be driven due to physical overhead restrictions. Drilled shafts also have applications under certain environmentally sensitive conditions.

The geometry of the drilled shaft will be determined by the soil conditions and the performance requirements. If lateral forces have to be resisted, modifications to the structural stiffness must be made to take the bending stress. The load capacity of drilled shafts is such that a single, large-diameter drilled shaft can take the place of a group of driven piles.

The flexibility of this type of foundation is such that axial and lateral loads can be resisted in a variety of soil conditions. The final decision, as to whether drilled shafts are better applied to a foundation problem than driven piles, must be based on the performance requirements and economic considerations.